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Energy cost and greenhouse gas emissions of a Chinese wind farm

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Abstract

Wind power is considered as one of the most promising renewable energy sources in China. Presented in this study is a life cycle analysis of energy performance and greenhouse gas emission for a typical wind farm in Guangxi, with different stages of manufacturing, transportation, and installation of mechanical components, operation and maintenance, and disassemble and disposal taken into account. Results show that the nonrenewable energy cost and greenhouse gas emission to generate 1 MJ of electricity for the grid are 0.046 MJ and 0.002 kg CO_2 equivalent, respectively. In consideration of the dominant power generation technology of coal combustion in China, the nonrenewable energy saving brought about by the concerned wind farm is estimated at 1.22E+7GJ during its twenty year operating period, while the reduced greenhouse gas emissions are as much as 1.03E+06 ton CO_2 equivalent. It is believed that this successful example can lend solid support to a future wide use of wind power in China.

Keywords: Embodied energy analysis; Greenhouse gas emission; Wind farm; China

1. Introduction

Wind farm construction in China started since mid 1980s. The manufacturing technologies and production capability of wind power equipment as well as wind power management in China have achieved great progress. More than 90% of 750kW wind turbines are domestic manufactured. Many experts believe that China will be central to the future of the global wind energy marked. According to the national Long- and Medium-term Plan on Renewable Energy, the total existing capacity of wind power will be expected up to 30GW by 2020 in China [1]. This paper aims to evaluate the nonrenewable energy (NE) performance and Greenhouse gas GHG emissions of a wind electricity production in China. It takes into account nonrenewable mass and energy flows and associated GHG emissions over the whole production process starting from wind turbines manufacturing and wind farm construction to the final disassembly and disposal. The analysis of the study can map nonrenewable energy flows

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and GHG emissions in fine detail and thus help identify nonrenewable energy intensive components. The results are compared with traditional coal power plant, and provides useful information for any Chinese electrical company in order to decrease the nonrenewable energy cost of wind farms and to minimize the GHG emissions due to the construction of new plants or the dismantling of old ones.

2. Methodology

To directly denote how many times of nonrenewable energy (NE) consumed in the process than the energy obtained, an indicator termed as nonrenewable energy investment in energy delivered (NEIED) is proposed to be

$$NEIED = NE / E_{out} \tag{1}$$

where NE is the nonrenewable energy used directly and indirectly in the production process, and E_{out} is the electricity output of a wind farm. NE can be calculated as

$$NE = \sum NE_i = \sum (Input_i \times N_i) \tag{2}$$

where NE_i denotes the nonrenewable energy used directly and indirectly in the production of *i*th inputs, $Input_i$ is the quantity of *i*th input energy and material flows to the whole chain of ethanol processes, and N_i , which expresses the unit primary nonrenewable energy demand directly and indirectly in the production or preparation of each input, is defined as the NE-intensity coefficient of the *i*th inputs. Such coefficients are evaluated by subtracting renewable energy inputs into the society in I-O analysis which is performed by Zhou [2].

Similarly, the GHG emissions ($GHG_{emission}$) associated with NE cost can be calculated as

$$GHG_{emission} = \sum (Input_i \times G_i) \tag{3}$$

where G_i expresses the unit directly and indirectly GHG emissions in the production or preparation of each input, is defined as the GHG-intensity coefficient of the *i*th inputs. Such coefficients can also be found in Zhou [2].

In addition, because the wind tower foundations take up a small area of land, the GHG emissions linked to land use change can be ignored in this study. And due to the data unavailability, possible emissions from the foundation into the environment have not been considered during the lifespan of the wind turbine.

3. Case study

The concerned wind farm locates in the Darong Mountain Resort (110°11’26″E~110°15’23″E, 22°51’36″N~22°52’49″N) in Yulin City, Guangxi Zhuang Nationality Autonomous Region, China, and covers a surface of 8.0 km2. The area does not include rural buildings and is near the main peak of Darong Mountain with a height of 1350m. The vegetation is constituted by spontaneous grass and small shrubs. The physical geological appearance is favorable, and no collapse and landslides occurred. The scheme proposes the installation of 24 wind turbines each with a generating capacity of 1.25MW, a hub height of 68m and a blade diameter of 64m (total height 100 m). Each wind turbine tower is connected to a 35 kW box-type transformer. The tower is installed on flat lay-bay and is firmly anchored with a 3.3m foundation. A substation with a 110 kV step-up transformer is constructed to decrease the line loss. And the control system is also located in the substation. Taking one year to construct, the project is designed with an operational life of 20 years.

There are 24 wind turbines with a total installed capacity of 30 MW. The net electricity to access grid for wind power will be 6.54E+07kW•h per year. Thus the annual electricity to access grid for each turbine will be 2.72E+06kW•h with an availability of 2179.5 hour per year. All of the detailed data referring the wind farm are from sources provided by the developer, China Hua Dian Corporation [3].

The wind farm studied in this paper is considered to be divided in six major parts, namely:

(1) Wind turbines components (rotors, nacelle, tower, and their sub-components);
(2) Substation components (transformer and control system);
(3) Transports;
(4) Building works (tower foundations, substation foundation, etc.);
(5) Operation and maintenance;
(6) Disassembly and disposal.

4. Results and discussion

As for the wind power process, the total NE cost for a 20 years wind farm is summed up to be 2.21E+08 MJ. The annual electricity output to assess grid is 6.54E+07kW•h. Then, NEIED is evaluated as 0.046, indicating that wind power requires 0.046 unit of nonrenewable energy to generate 1 unit of electricity, and revealing a high renewability of the process. Dividing total NE cost by the electricity to access grid net, payback period for the energy investment has been found as 0.94 year. Analysis of the results shows that wind turbines (41%) and the building work (50%) are the two single largest contributors, which together take up 91% in the total NE cost of the considered wind farm.

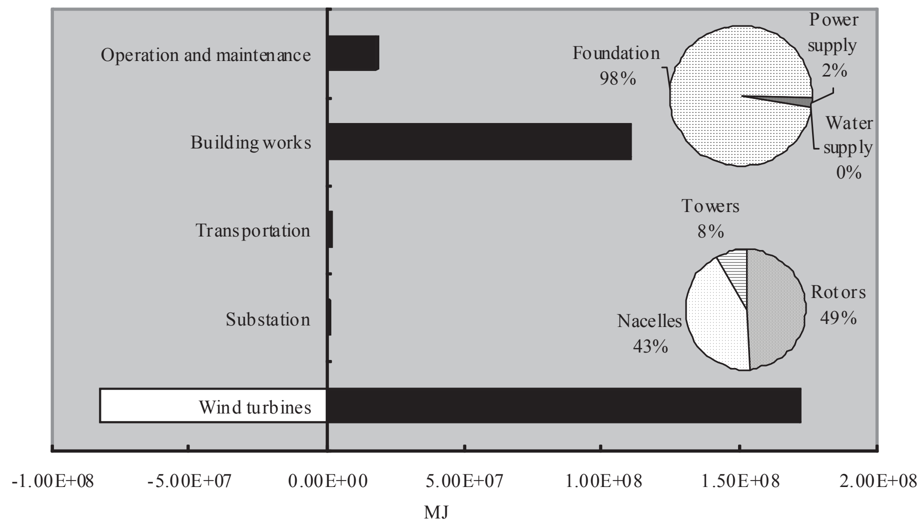

Fig.1. NE cost of a Chinese wind farm.

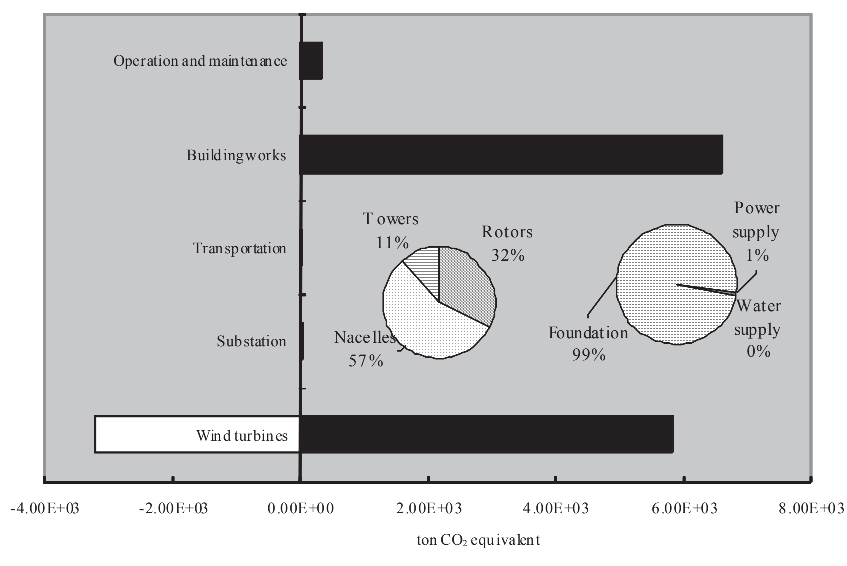

Fig.2. GHG emissions of a Chinese wind farm.

Accounting of GHG emissions caused due to manufacturing and operation of the wind farm has been done in a way similar as for the NE analysis (see Figure 2). The total GHG emissions for a 20 years wind farm are summed up to be 9930 ton CO_2 equivalent. An embodied GHG emission of 0.002 kg CO_2 equivalent/MJ is found for the wind farm. Analysis of the results shows that 67% of the total GHG emissions are caused in the building works, as well as

30% in the manufacture process of wind turbines. The GHG emissions generated in the operation and maintenance stage take up 3%.

In a rough estimation, the national average coal consumptions in generation of the thermal power plant are 356 g/kWh; the service power consumption rate is 7.1%; the average energy line loss rate is 7.52%, provided by CESY [4]. All of these data give a national average NE intensity of thermal power of 2.64 MJ/MJ, and a typical GHG emission coefficient of 0.22 kg CO_2/MJ. The coal power system therefore tends to consume about 54 times of NE and 110 times of GHG emissions as compared to the considered wind farm for per unit generation of electric power. Meanwhile, 2.59 MJ of NE and 0.218 kg equivalent CO_2 are saved per MJ of wind electricity output. Thus the NE saving during 20 years of operating time have been estimated as 1.22E+7GJ, while the saved GHG emissions are 1.03E+06 ton equivalent CO_2.

5. Conclusion

Briefly, the most important results of the analysis are the calculation of a total NE requirement of 0.046 MJ/MJ and a global warming potential of 0.002 kg CO_2 equivalent/MJ kg. Meanwhile, in contrast to coal power plant in China, the NE saving during 20 years of operating time have been estimated as 1.22E+7GJ, while the saved GHG emissions are 1.03E+06 ton equivalent CO2 in the considered wind farm. But this does not mean that it is not necessary to continue investigating and raising our knowledge of this technology, especially if we consider the huge increase and expected future growth of wind power. One area of special relevance is the need to improve the environmental impact of the various manufacturing processes involved in making the turbine and its components. To reach this goal quickly and effectively it is vital to have the cooperation and interest of the various manufacturers and Chinese government. This paper will be useful for the wind turbine manufacturer, generating members and decision makers.

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